Flue Gas CO_2 Capture

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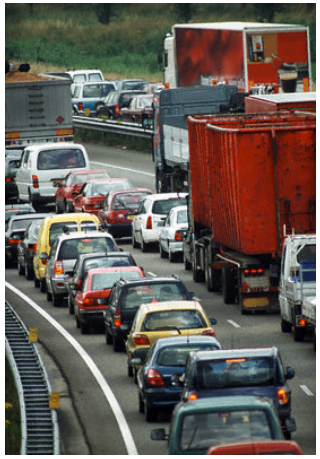
O=C=O Carbozyme Inc.

24B metric tonnes annually worldwide
25% from the U.S.



Transportation

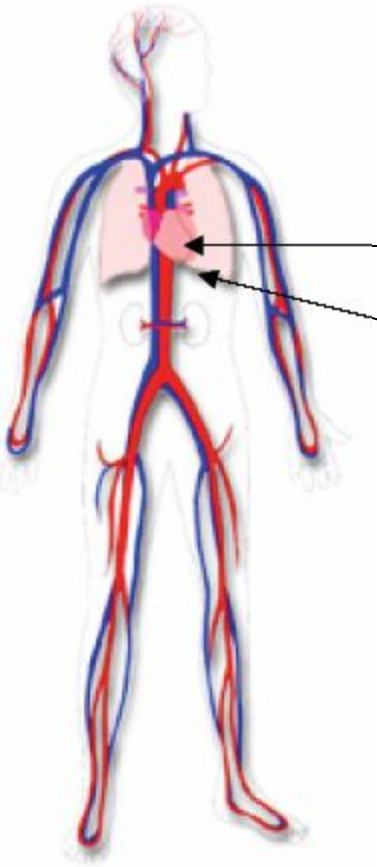
Commercial

Industrial

Residential

Carbozyme Inc.

Technology- Biomimetic Approach

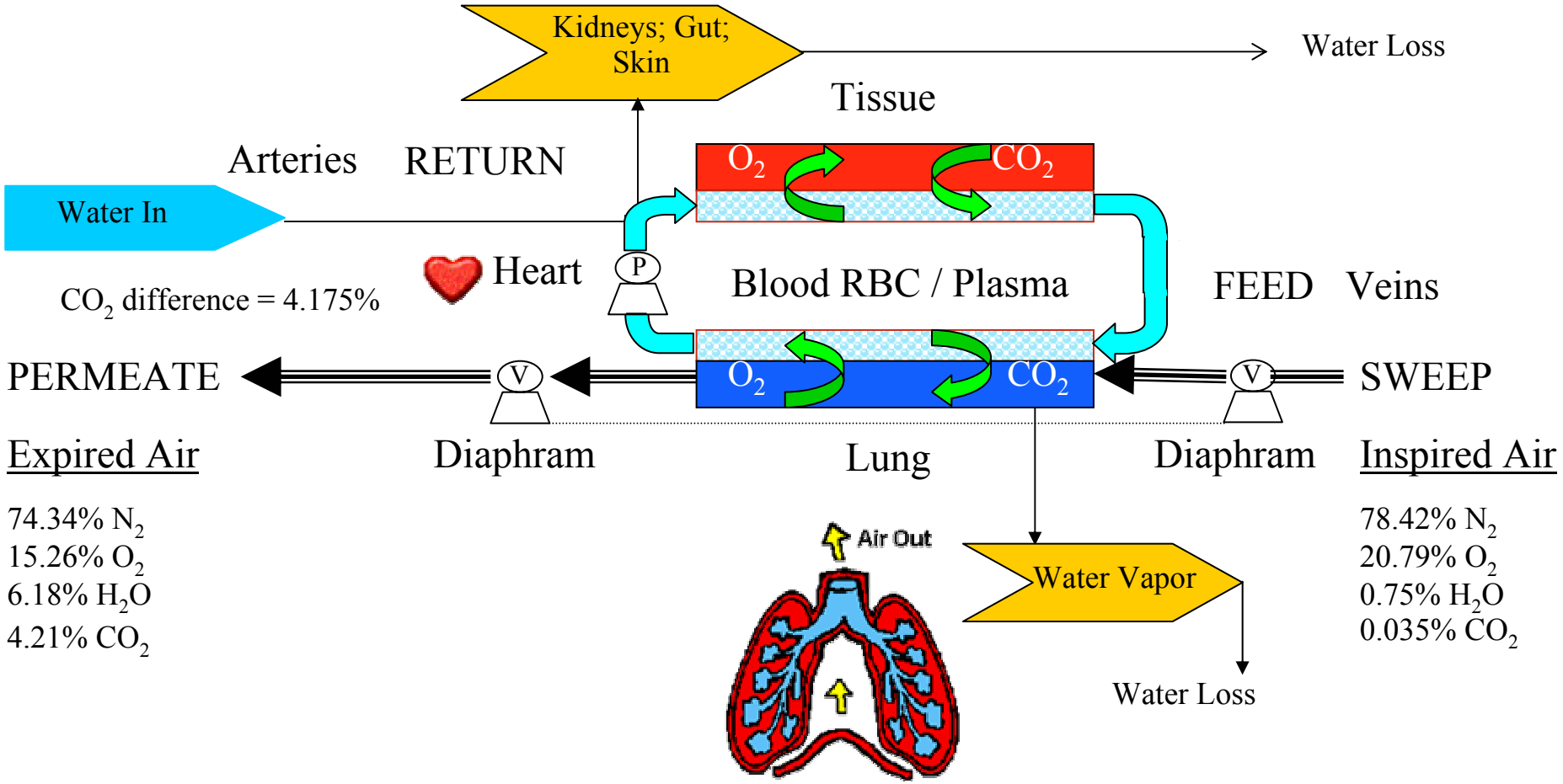


As seen by the Anatomist

Cardio-vascular / Cardio-pulmonary Systems

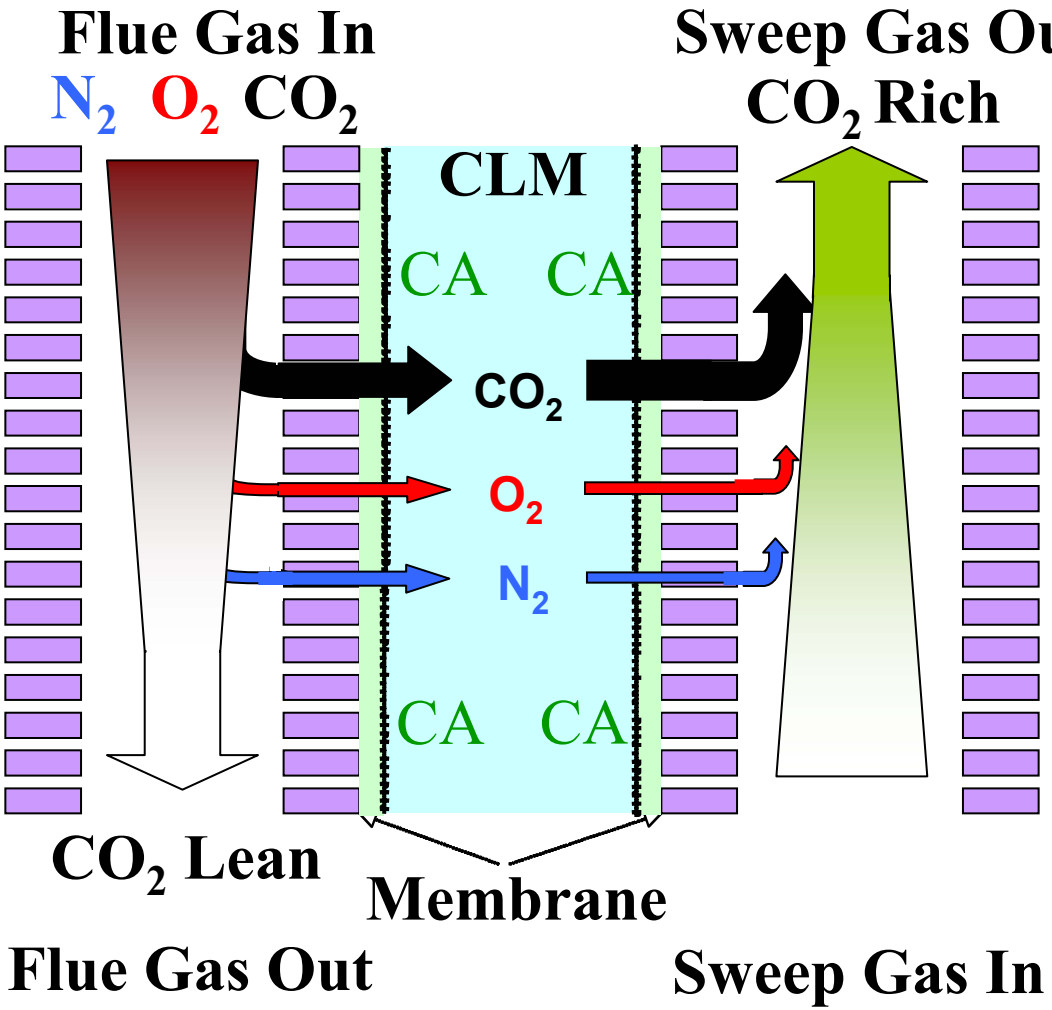
The CO_2 management strategy of most animals

Chemical Engineer's Approach



The Carbozyme Permeation Process

CA = Carbonic Anhydrase

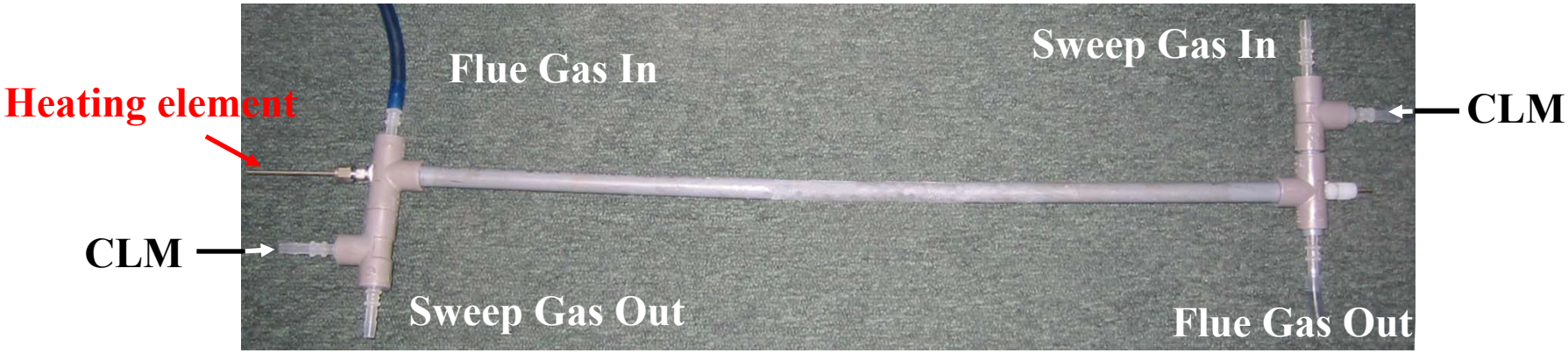


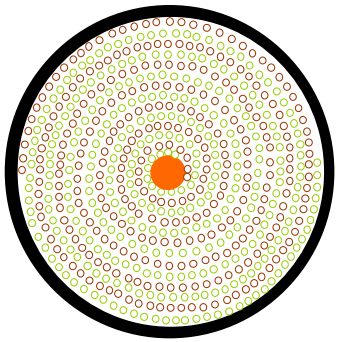
Carbozyme Permeator Modules

Carbozyme Permeator

Enzyme-based, Dual Hollow Fiber

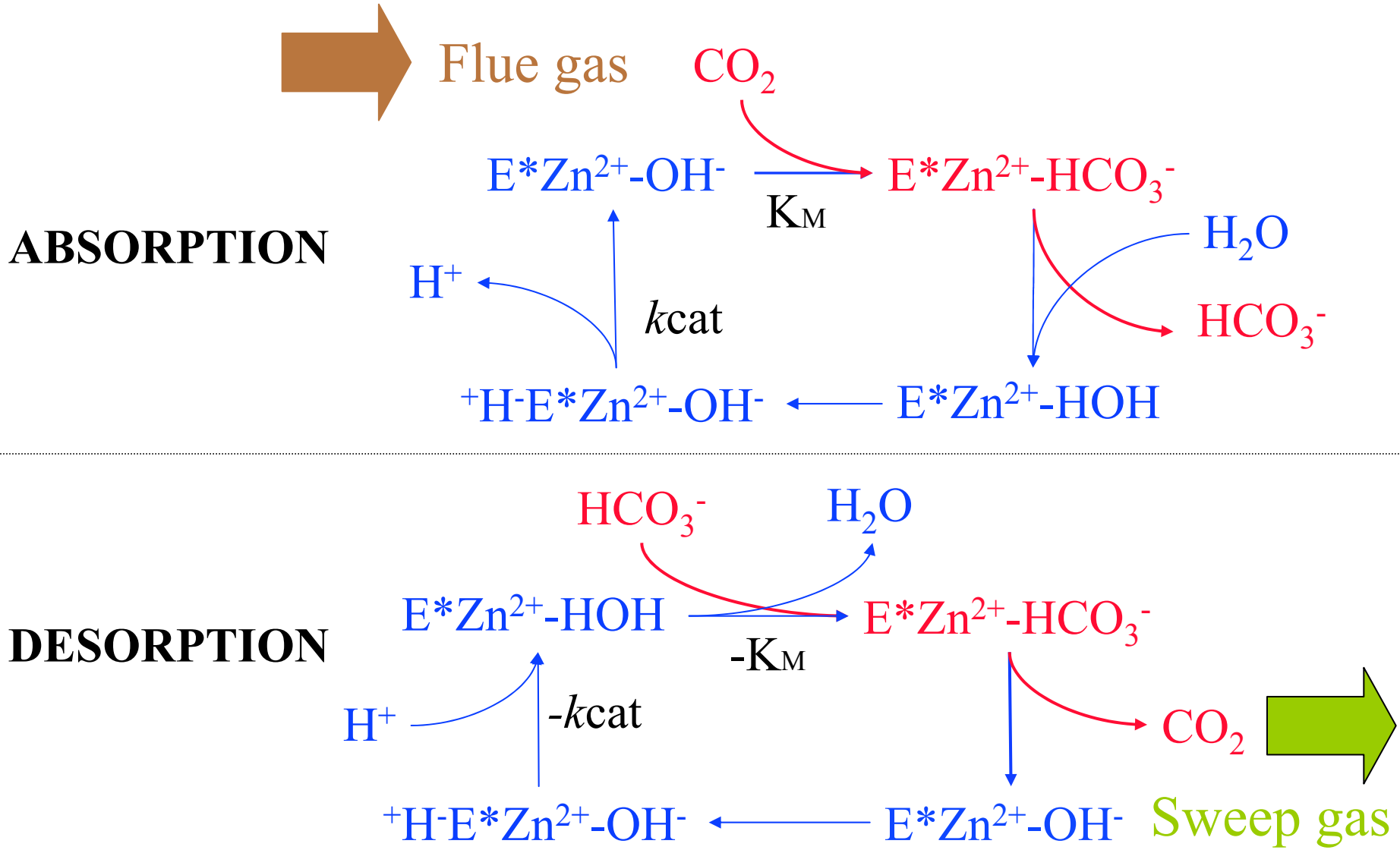
Contained Liquid Membrane Permeator



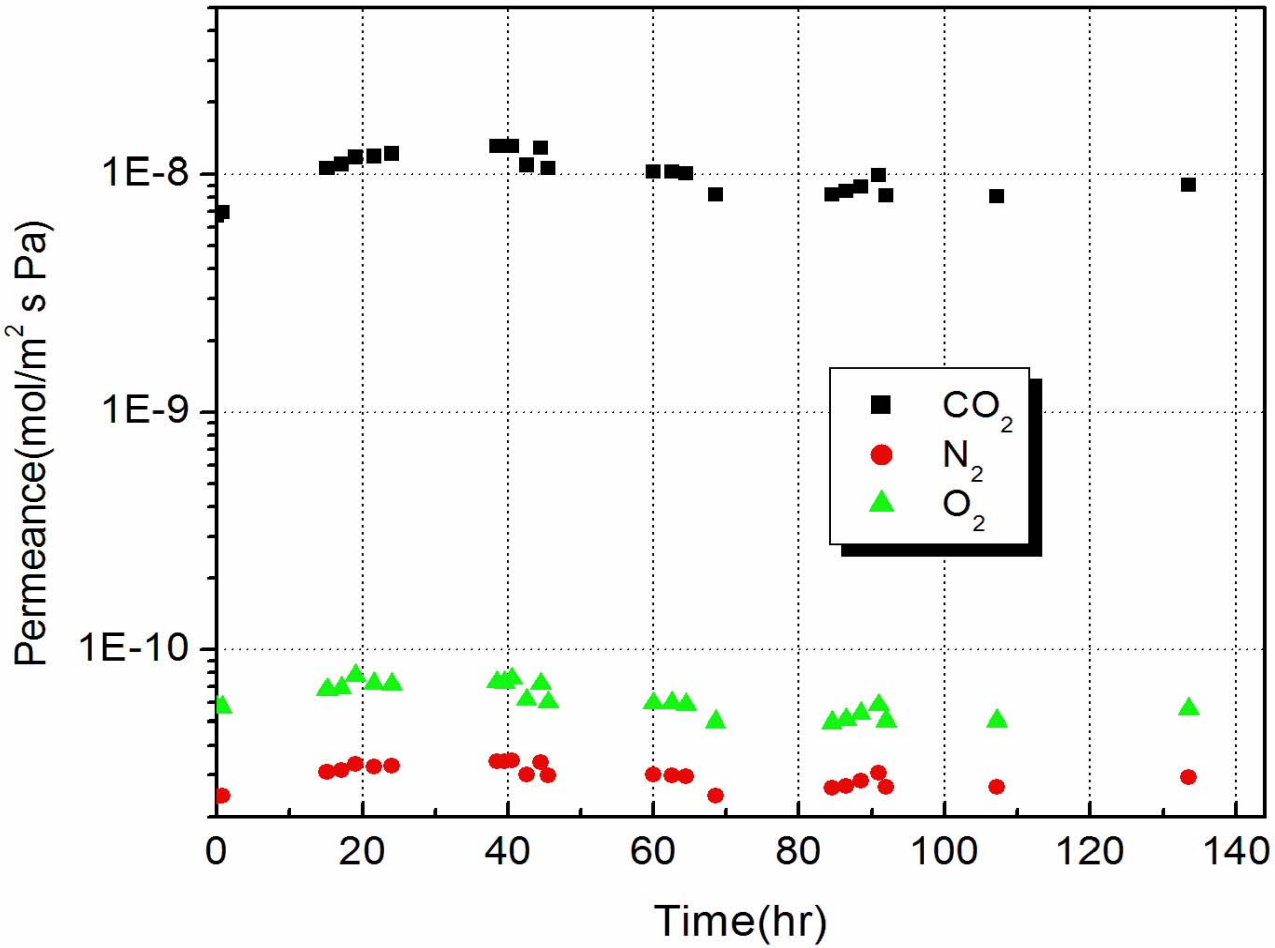


- **Feed / Retentate**
- **Permeate / Sweep**
- **Heating element**

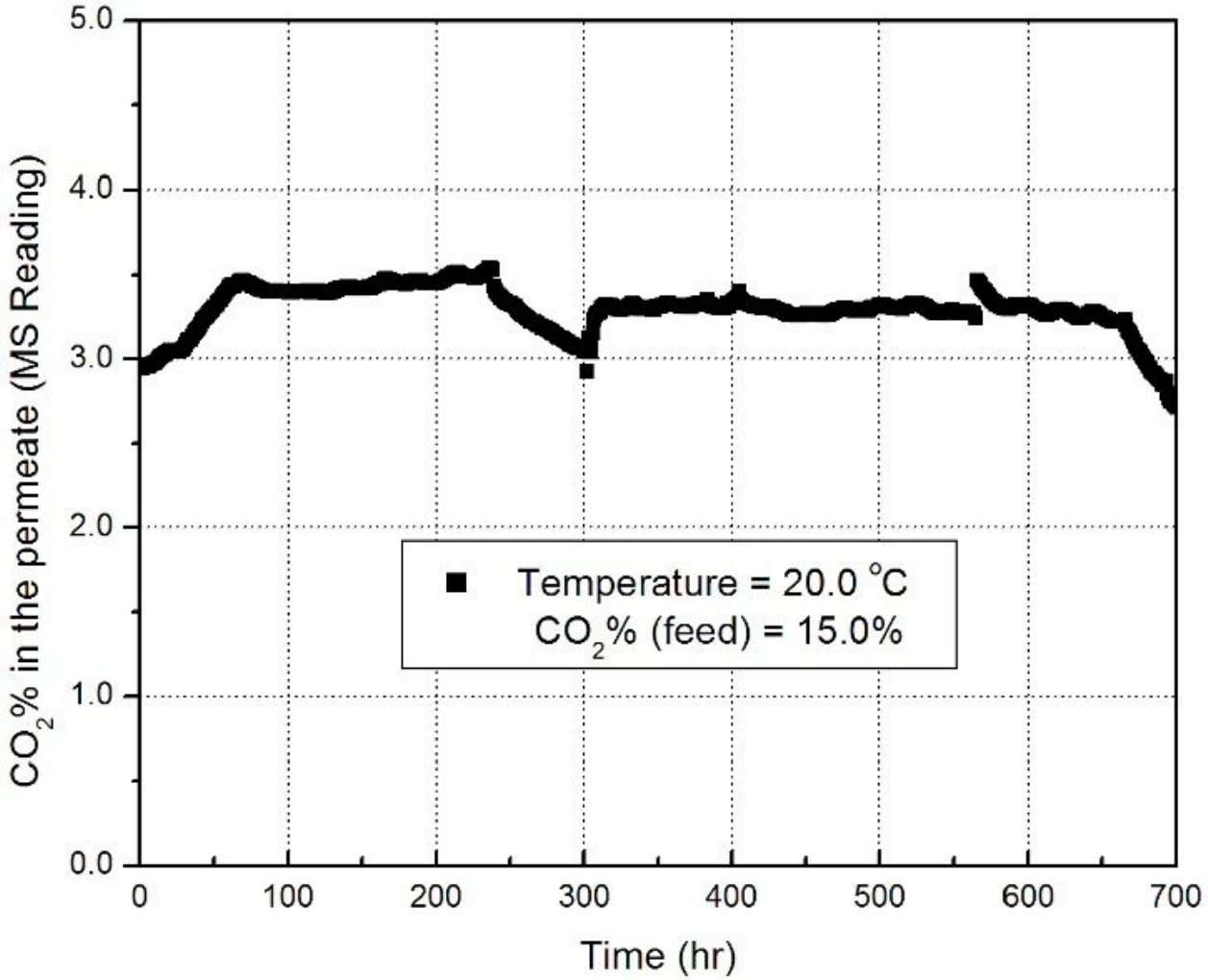
2 x 148 fibers
Length = 55.2 cm
O.D. = 300 µm
I.D. = 200µm
Total Area = 0.154 m^2


Flue gas
CO_2
E^*Zn^{2+}-OH^-
K_M
E^*Zn^{2+}-HCO_3^-
ABSORPTION
H_2O
H^+
HCO_3^-
kcat
^+H-E^*Zn^{2+}-OH^-
E^*Zn^{2+}-HOH
HCO_3^-
H_2O
E^*Zn^{2+}-HOH
E^*Zn^{2+}-HCO_3^-
DESORPTION
$-K_M$
H^+
-kcat
CO_2
^+H-E^*Zn^{2+}-OH^-
E^*Zn^{2+}-OH^-
Sweep gas

Permeator Performance Selectivity



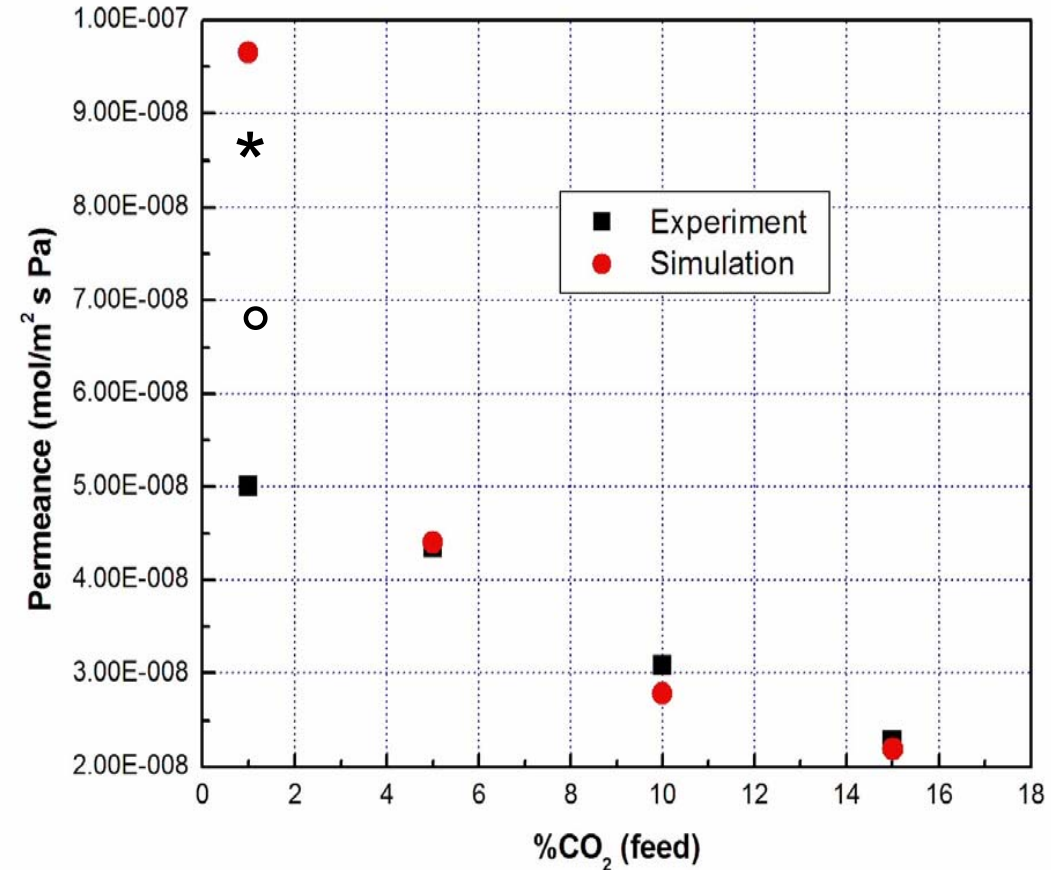
Long-Term Stability



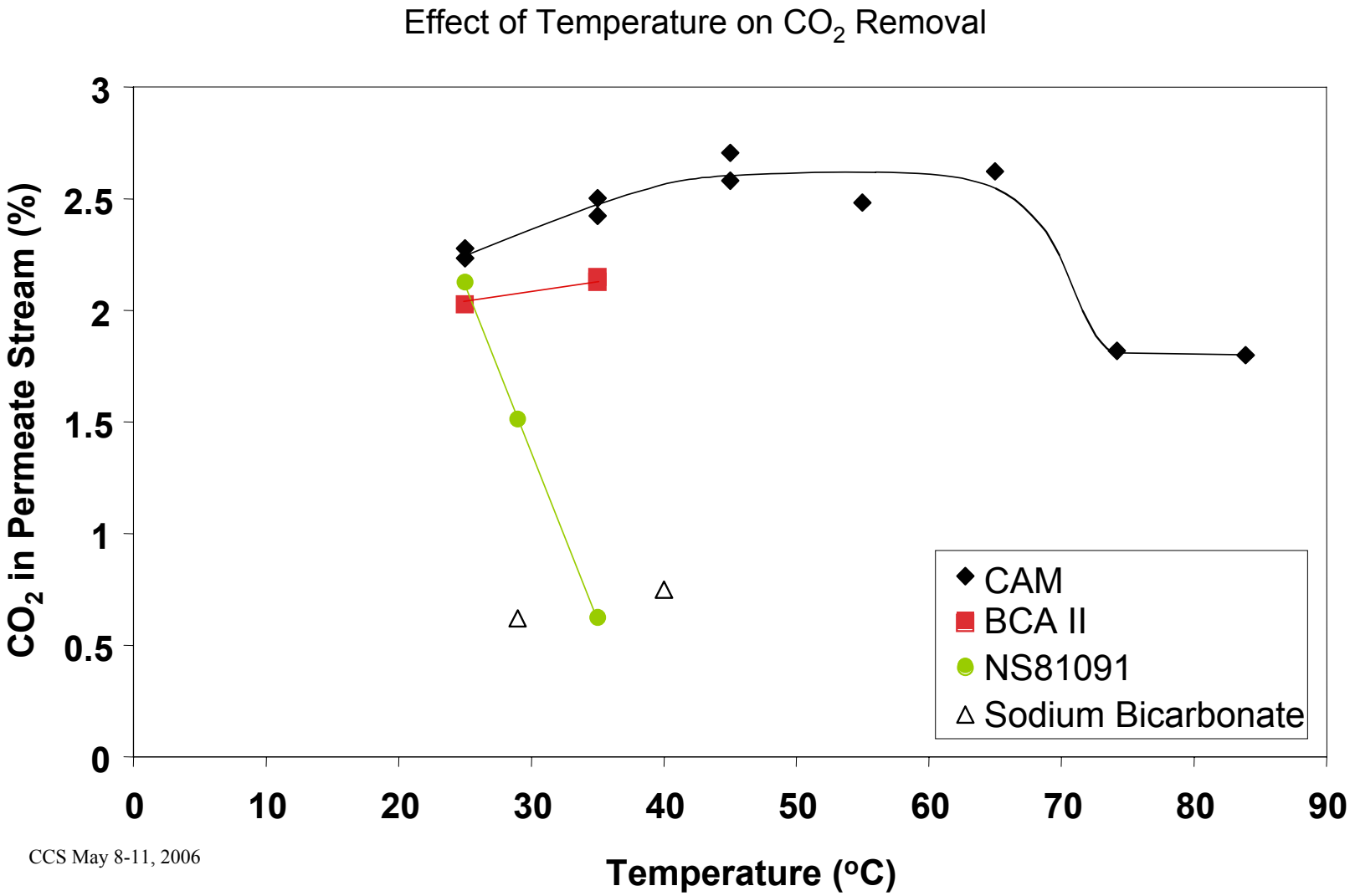
Model Validation

- Celgard X40-200 micro-porous hollow fiber
- # of feed fibers = # of sweep fibers
- nominal porosity = 30%
- Total membrane surface area = 0.19 m^2
- Effective membrane area = 0.076 m^2
- No CLM pumping

In the simulation
*k*cat = 1E6 (s^{-1})



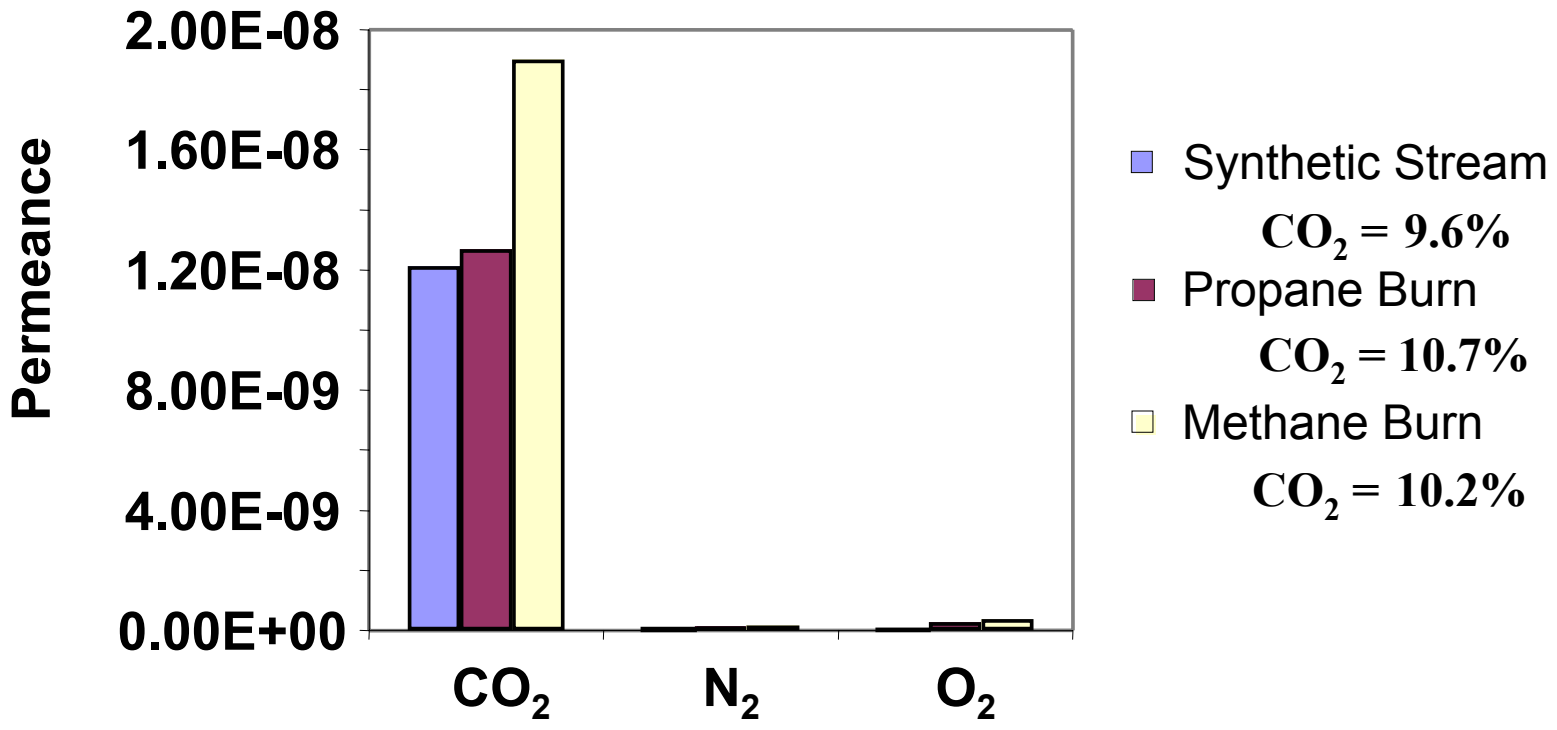
CA Isozyme Comparison



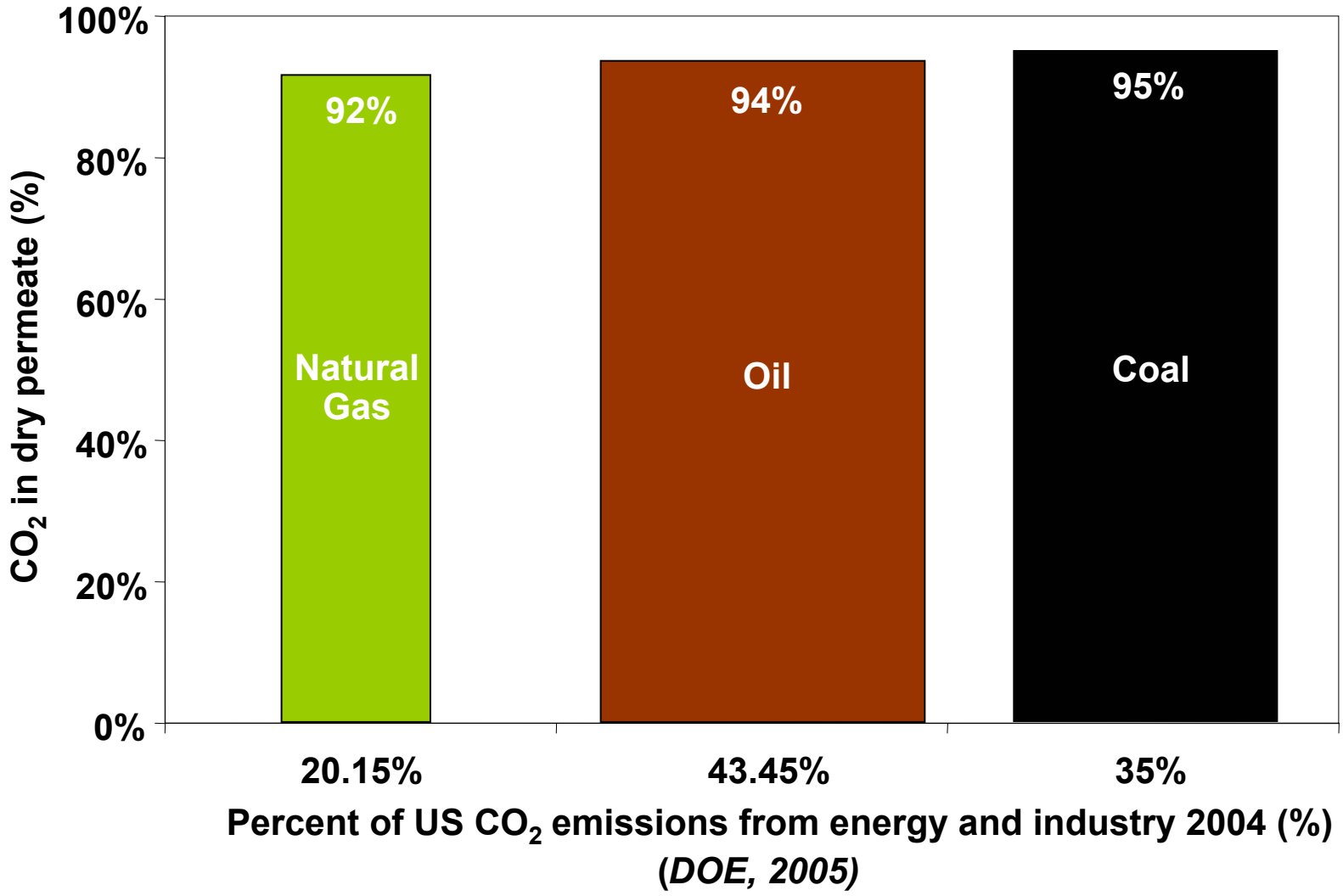
Lab Test Apparatus

Methane/Propane Data

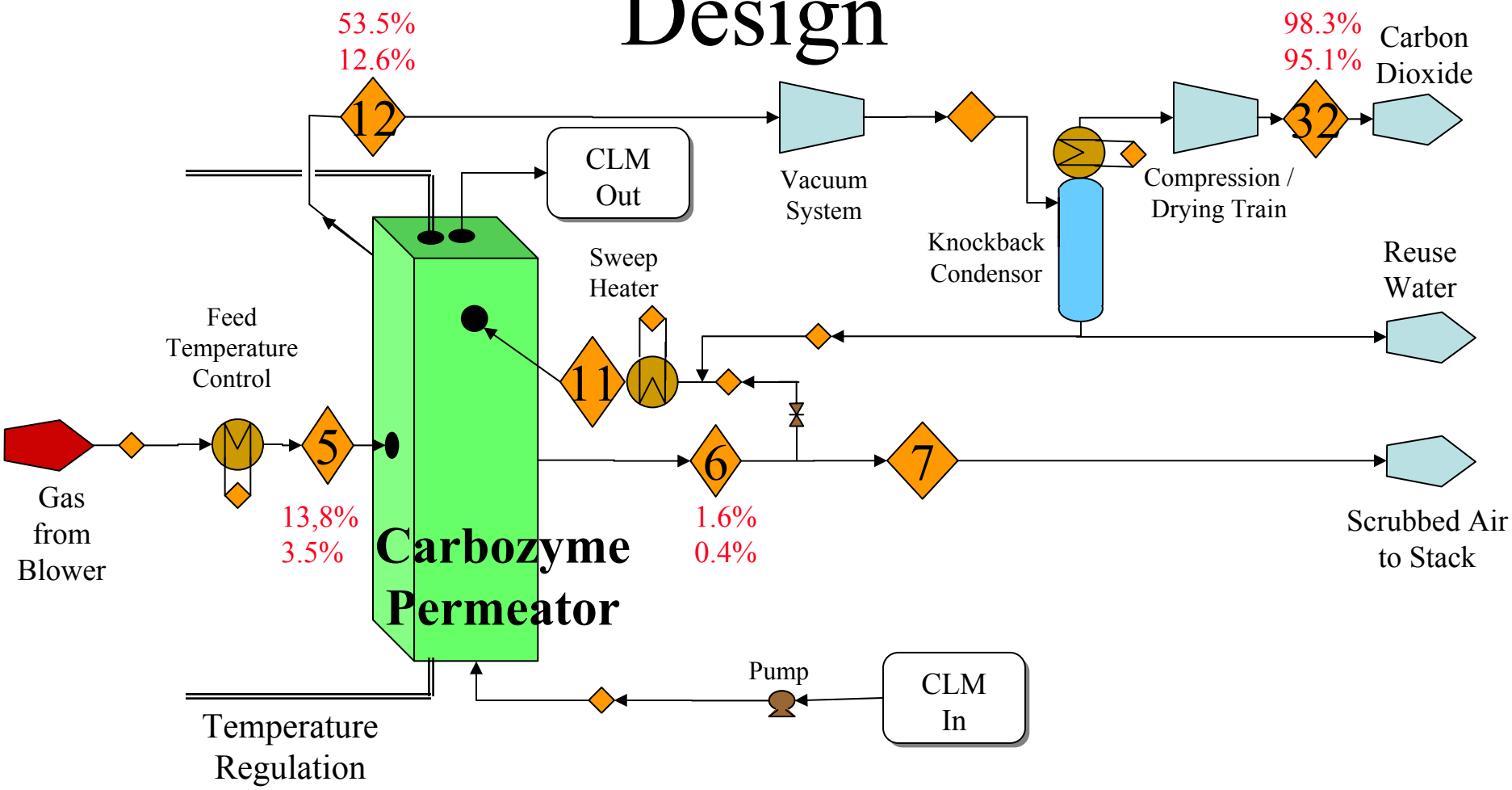
Pure Gas vs. Combustion Products



Flue Gas CO_2 Capture



Carbozyme Process Engineering Design



Coal

O
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Carbozyme Inc.
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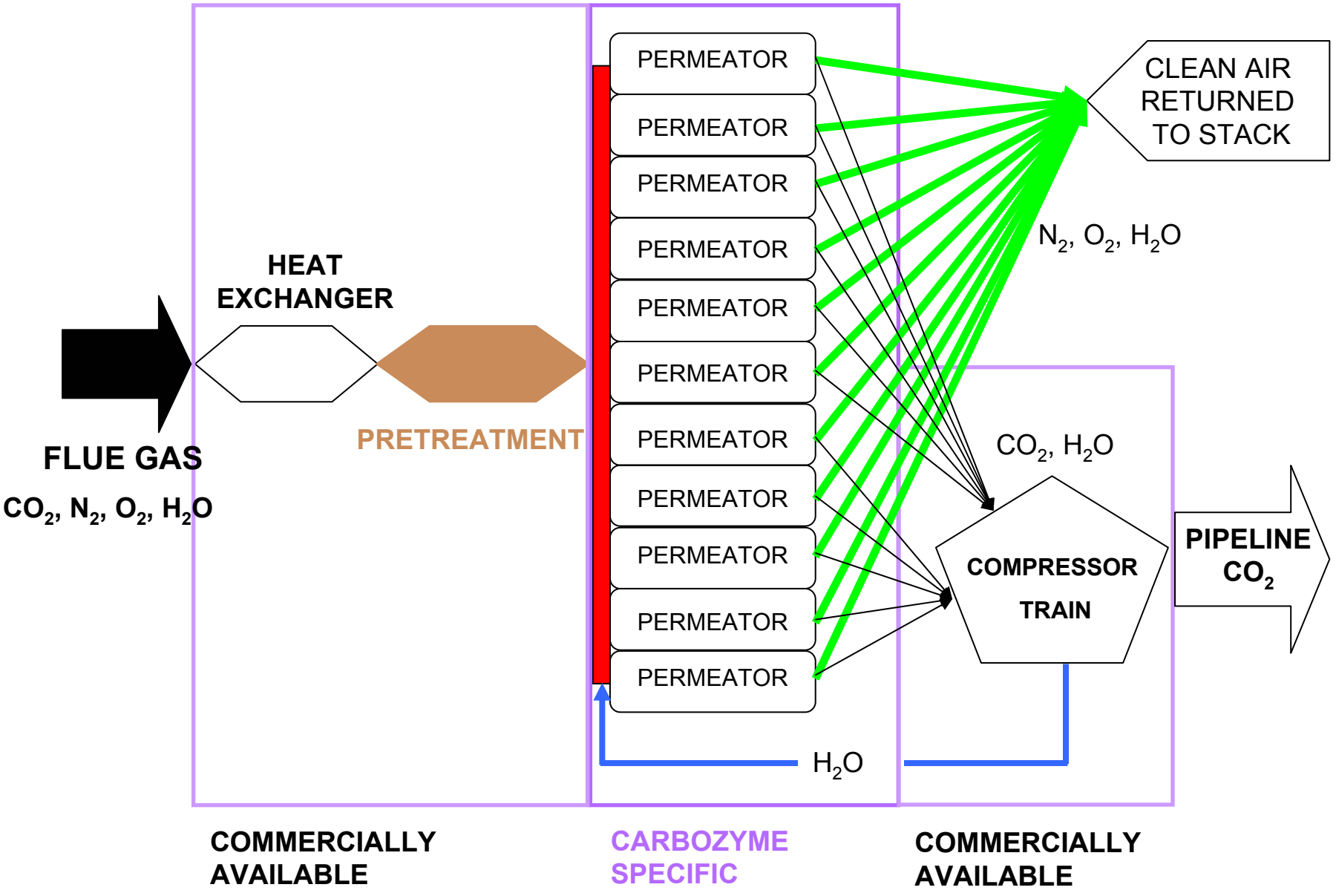
EPRI Coal Case 7C with Carbozyme Permeator

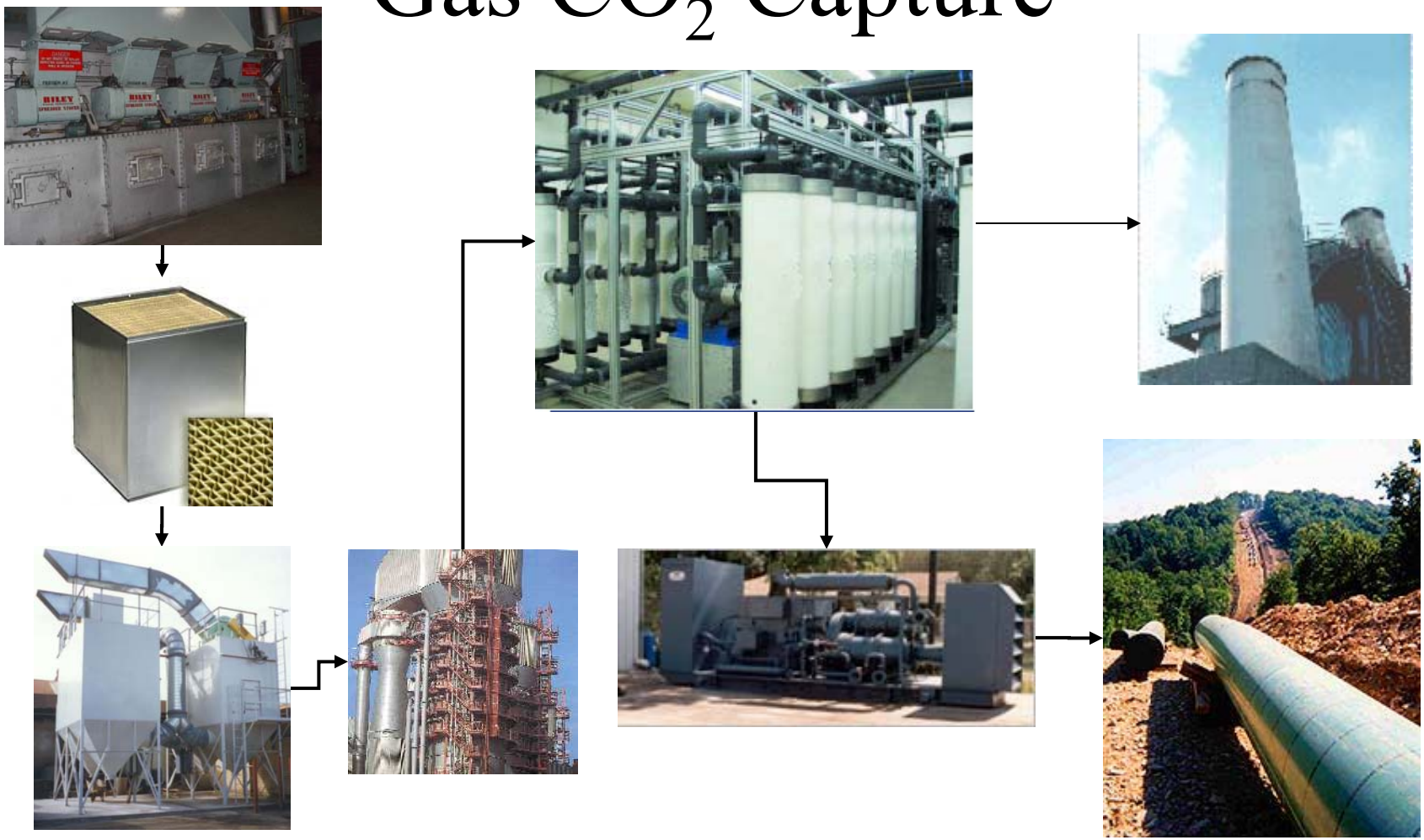
Component	MW	Permeator Feed - Stream # 5			
		Vapor mole/sec	Composition Vol%	Partial Pressure Pa	Mass Flow gm/min
CO2	44.0	2,456.6	13.8%	14,335.32	6,485,217
O2	32.0	535.0	3.0%	3,121.93	1,026,796
H2O	18.0	1,813.5	10.2%	10,582.67	1,959,650
N2	28.0	12,785.4	72.0%	74,608.74	21,489,675
CO	28.0	1.5	0.0%	8.52	2,454
HCl	36.5	0.1	0.0%	0.30	113
SO2	64.0	4.5	0.0%	26.47	17,428
SO3	80.0	0.2	0.0%	1.00	825
NOx	46.0	6.0	0.0%	35.09	16,593
Argon	39.9	160.4	0.9%	936.19	384,533
Total		**17,763.1**	**100.0%**	**103,656**	**31,383,283**
Temp (¡C)					55
Pressure (Pa)					103,656
RH					67%
Flow (LPM)					28,035,621

EPRI Coal Case 7C with Carbozyme Permeator

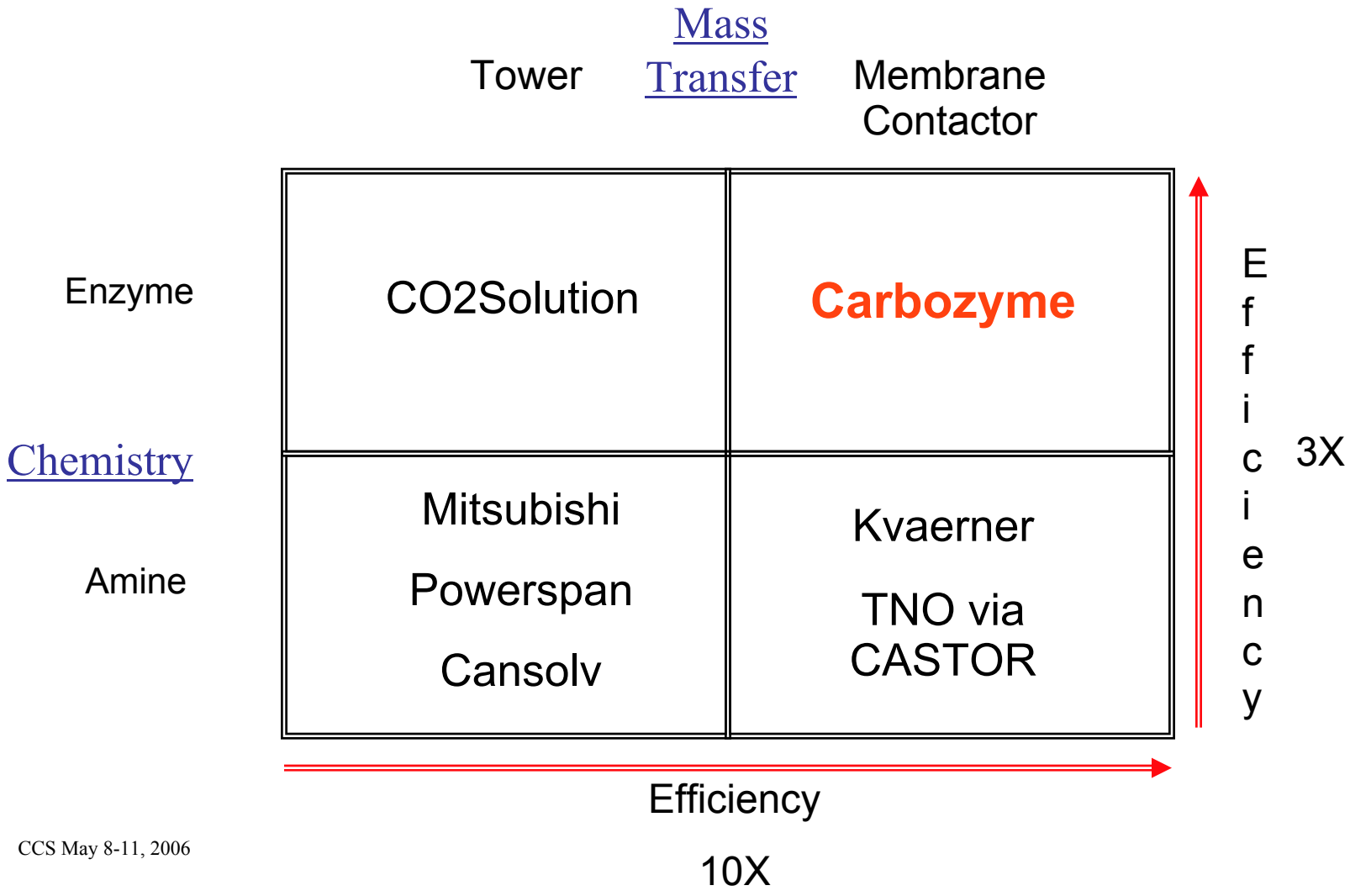
Component	Compressed/Dried CO2 - Stream # 32			
	Vapor mole/sec	Composition Vol%	Partial Pressure Pa	Mass Flow gm/min
CO2	2,212.1	98.3%	8,309,551	5,839,933
O2	2.8	0.1%	10,684	5,459
H2O	0.1	0.0%	544	156
N2	34.3	1.5%	129,027	57,734
CO	0.0	0.0%	0	0
HCl	0.0	0.0%	0	0
SO2	0.0	0.0%	1	1
SO3	0.0	0.0%	0	0
NOx	0.0	0.0%	1	1
Argon	0.4	0.0%	1,619	1,033
Total	**2,249.9**	**100.0%**	**8,451,427**	**5,904,317**
Temp (¡C)				50
Pressure (Pa)				8,451,427
RH				4%
Flow (LPM)				42,890


PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
PERMEATOR
CLEAN AIR RETURNED TO STACK
N_2, O_2, H_2O
HEAT EXCHANGER
PRETREATMENT
FLUE GAS
CO_2, N_2, O_2, H_2O
CO_2, H_2O
COMPRESSOR TRAIN
PIPELINE CO_2
H_2O
COMMERCIALLY AVAILABLE
CARBOZYME SPECIFIC
COMMERCIALLY AVAILABLE

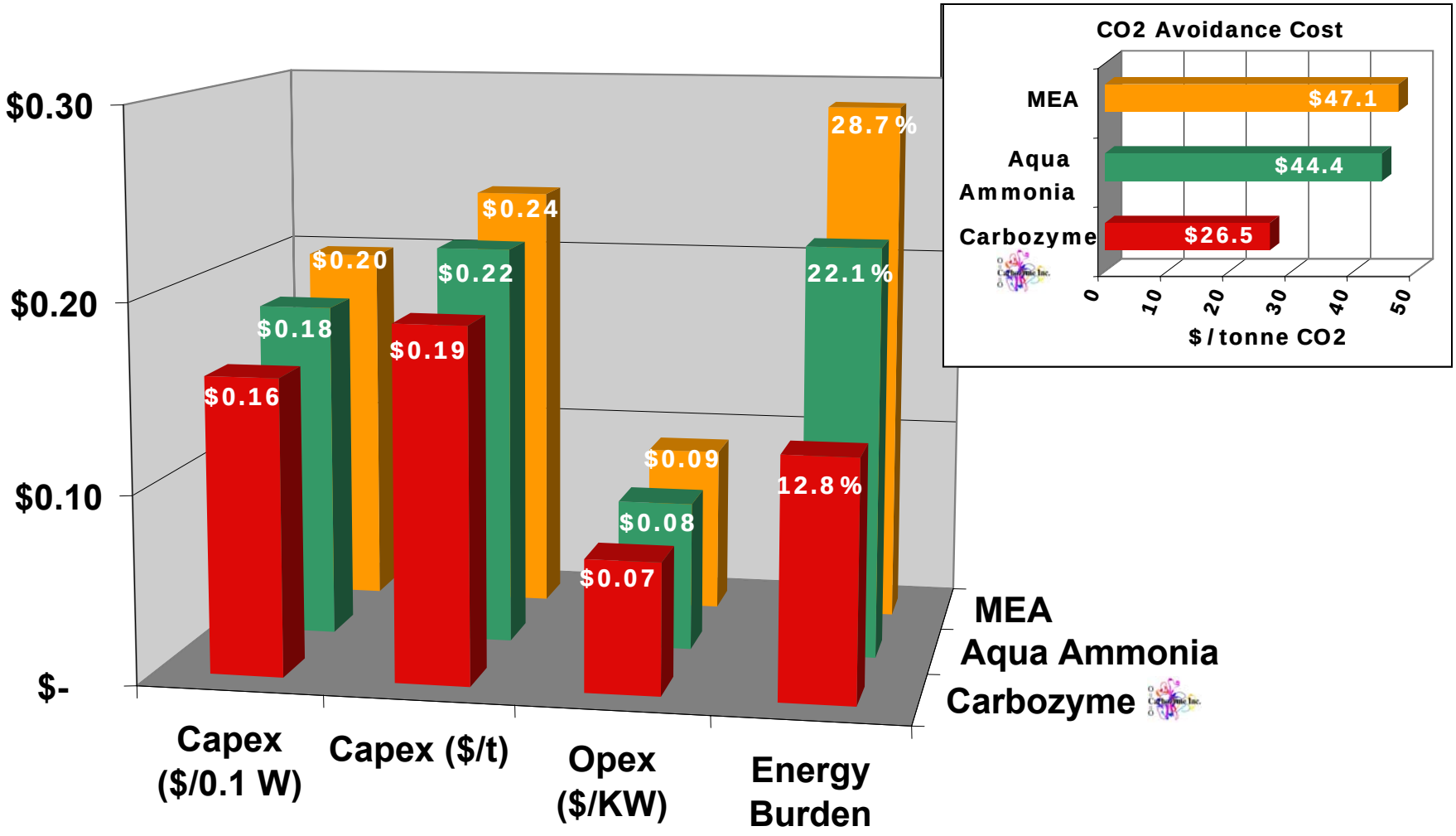
Pictorial Representation of Flue Gas CO_2 Capture



Direct Competition: Too Expensive



Cost Advantage - Coal Flue Gas CO_2 Capture



Based on EPRI, 2000

Industry (DOE) Performance Goals

For Coal Fired Electric Generators

- Capture 90% of the CO_2 in the flue gas stream
- Achieve 95% purity in the product
- Impose a cost burden of less than 20% increase in the cost of energy services by 2007; 10% by 2012

Carbozyme meets or exceeds these criteria, TODAY

The Carbozyme Benefit

Acknowledgements

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